D3.4: Report on KPIs to be embedded in the TREASURE circularity web platform

30/11/2022 (M18)

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EXECUTIVE SUMMARY

This deliverable describes the indicators selected for the Circularity web application of the TREASURE platform. In total 26 indicators have been selected, based on the interest of each of the stakeholders of the automotive value chain (manufacturers, dismantlers and recyclers), the limitations of available information and the ease of collecting information from the stakeholders.

Five headline indicators common to the three modules of the Circularity Web application have been proposed. These indicators are: metal use, plastic use, recyclability, disassemblability, and a global indicator that weighs the other indicators. For the first four indicators, are numerically assessed on a scale of 1 to 100. The global indicator is assessed employing stars (1 to 5 stars).

Secondary indicators, adapted to the needs of each stakeholder and therefore incorporated in one of the three modules of the Circularity Web application, are then described. These secondary indicators are different in nature, and can be classified as economic, environmental, criticality, recyclability and disassemblability indicators. Social indicators are out of the scope of the Circularity Web application, but are taken into account in other parts of the TREASURE platform.

The proposed indicators have been incorporated into the first version of the platform. However, some changes might arise as the project progresses.

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1. Introduction

This deliverable is the result of task 3.4 – *"Eco-design, disassemblability, reusability and recyclability guidelines integration with CE indicators"*, which deals with the indicators that will be included in the Circularity Web application of the TREASURE platform.

The platform will connect different stakeholders around vehicles, from manufacturers to recyclers going through consumers and dismantlers. It will also offer information to encourage circular economy practices among the whole value chain. The platform includes the so-called Circularity Web application, where specific information devoted to increase resource efficiency of each end user in the automotive industry is presented. In particular, the circularity web application is composed of three modules (see Fig. 1): 1) eco-design; 2) disassembly and 3) recycling modules, with the aim to (1) assesses the resource efficiency of designs, which is valuable for manufacturers; (2) encourage the dismantling of car parts providing information about the economic value of the disassembled parts and information on how to dismantle them; (3) promote the recyclability of car parts by giving information about the best recycling routes to recover them with corresponding recovery rates; (4) provide feedback from recyclers and dismantlers to manufacturers to improve future designs.

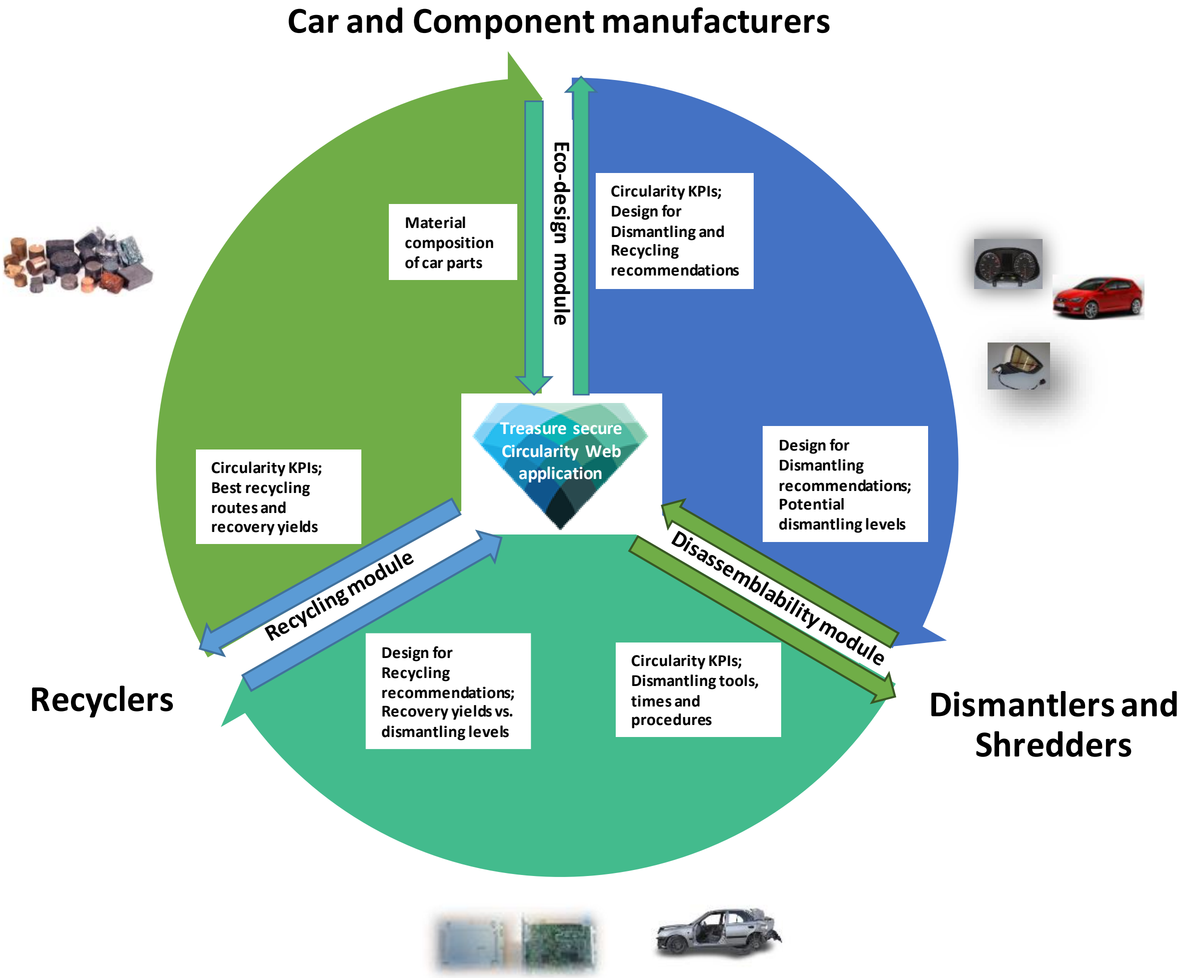

Figure 1: overview about the Circularity Web application within TREASURE platform

The information provided to the different stakeholders is in the form of indicators (KPI). Such indicators should be specifically addressed to cover the necessities of manufacturers, dismantlers and shredders and recyclers. This deliverable aims at determining such indicators, considering the information that can be effectively shared and/or produced, with the knowledge gathered during tasks 3.1, 3.2, and 3.3, and considering the indicators defined in other work packages. Accordingly, the structure of this document is the following.

Section 3 presents a review of indicators defined in previous project activities (mainly WP2), from which a selection of suitable indicators for the Circularity Web application is made.

Section 4 presents the complete set of indicators that have been preliminarily selected for each module of the Circularity Web application. The indicators are divided into headline indicators (common for all modules of the circularity web application) and secondary indicators (designed explicitly for the stakeholder group addressed). All KPIs will be used in the final version of the TREASURE platform that will be presented in D4.8 (M33).

Section 5 offers the list of **headline indicators** that are the base to score a car part considering its resource efficiency in terms of the criticality of the metals used, plastic use, recyclability and disassemblability aspects.

Sections 6 to 8 describe the **secondary indicators**, divided into the respective Circularity Web application modules where they are embedded.

It should be mentioned that this deliverable does not purposively address social indicators, as these are out of the scope of the Circularity Web application. That said, the platform does include the social dimension of circular economy practices in the automotive industry, which are addressed in detail in D2.2 *"Sustainability advisory methodology definition".*

2. Relation with other project activities

Deliverable 3.4 must offer a complete set of indicators to be embedded in the Circularity Web application of TREASURE platform. To that end, a comprehensive review of circularity & sustainability assessment methods and indicators was carried out in WP2. The most useful and accomplishable indicators are selected from that list, considering the knowledge gathered during the activities performed within WP3, regarding the criticality, disassemblability, and recyclability assessments of car parts.

Figure 2 presents the relationship between D3.4 and other project activities. The circularity web application of the platform is developed under WP4 (TREASURE platform design, development & integration), being D4.7. This first platform version contains mock-ups of the disassemblability, recyclability, and eco-design modules.

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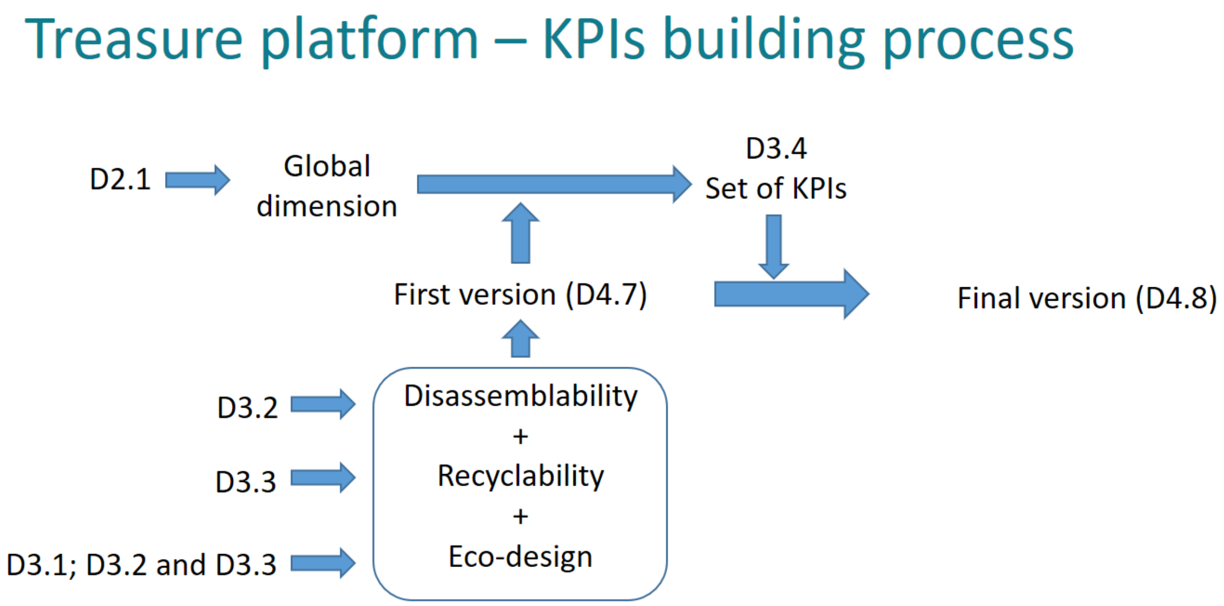

Figure 2: TREASURE KPIs building process

3. KPIs defined in other project activities

Table 1 summarizes potential KPIs for the Circularity Web application identified and presented in different project deliverables.

Table 1: Summary of potential KPIs to be used in the Circularity Web application

ECONOMIC		
Indicator	**Unit**	**Link with other TREASURE tasks**
Personel cost	€/h	D1.4; D2.1; D2.2; D4.7
Raw material cost	€	D2.1; D2.2; D4.7
NPV	€	D1.4; D2.1
IRR or ROI	%	D1.4; D2.1
Car part cost	€	D4.7
Energy consumption	kWh/t	D1.4; D2.1; D2.2
ENVIRONMENTAL		
Indicator	**Unit**	**Link with other TREASURE tasks**
Global warming potential/Climate change	kg CO2-eq/LCA-derived unit	D1.4; D2.1; D2.2;
Acidification	LCA-derived unit	D1.4; D2.1; D2.2;
Eutrophication – terrestrial	LCA-derived unit	D1.4; D2.1; D2.2;
Eutrophication – aquatic, fresh water	LCA-derived unit	D1.4; D2.1; D2.2;
Eutrophication – aquatic, marine	LCA-derived unit	D1.4; D2.1; D2.2;
Photochemical ozone formation, human health	LCA-derived unit	D1.4; D2.1; D2.2;
Ozone depletion	LCA-derived unit	D1.4; D2.1; D2.2;
Resource use – fossils	LCA-derived unit	D1.4; D2.1; D2.2;
Water use	LCA-derived unit	D1.4; D2.1; D2.2;
Resource use – minerals and metals	LCA-derived unit	D1.4; D2.1; D2.2;

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Land use	LCA-derived unit	D1.4; D2.1; D2.2;
Eco-toxicity – aquatic, fresh water	LCA-derived unit	D1.4; D2.1; D2.2;
Human toxicity – non cancer	LCA-derived unit	D1.4; D2.1; D2.2;
Human toxicity – cancer	LCA-derived unit	D1.4; D2.1; D2.2;

RECYCLING

Indicator	**Unit**	**Link with other TREASURE tasks**
Recycling index of the entire car part	%	D1.4; D2.2; D3.3; D4.7
Recycling index of each metal	%	D1.4; D2.2; D3.3; D4.7
Energy recovery	MWh/t	D3.3; D4.7
Plastic characterisation	%	D.4.7
Use of thermosettings	%	D4.7
Use of thermoplastics	%	D4.7

DISMANTLING

Indicator	**Unit**	**Link with other TREASURE tasks**
Difficulty level for Level 1	High/Medium/Low	D1.4; D2.2; D3.2; D4.7
Difficulty level for Level 2	High/Medium/Low	D1.4; D2.2; D3.2; D4.7
Disassembly time	min	D1.4; D2.2; D3.2; D4.7
Material composition	%	D4.7

CRITICALITY

Indicator	**Unit**	**Link with other TREASURE tasks**
Rarity of the entire car part	kJ	D1.4; D2.2; D3.1; D4.7
Rarity intensity of a given car part	kJ/kg	D2.2; D3.1
Rarity of a given metal	kJ & %	D2.2; D3.1; D4.7
Weight of a given metal	g	D3.1; D4.7
World recycling rates (WRR)	%	D4.7
Automobile sector demand over annual production	%	D4.7
Total cumulative demand over known reserves	dimensionless	D4.7
Supply risk	dimensionless	D4.7
Strategic Metal Index (SMI)	dimensionless - from 0 to 100	D4.7
Most important world producer	name of the country	D4.7
Production quote of this country	%	D4.7

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4. Selected KPIs and links with TREASURE platform

From the set of indicators presented in the previous section, the selected ones are shown in Table 2. This selection has been carried out considering the limitation of information that can be obtained from each stakeholder. It should be mentioned that the basis of the Circularity Web application is the Material Information System Sheet (MISS) of the different car parts, which manufacturers upload into the Treasure Platform. Many of the proposed indicators are therefore built from MISS. As shown in Table 1, five headline indicators have been selected, which are shared in all modules. The rest are secondary indicators explicitly developed for each module, considering the specific needs of each stakeholder, i.e. dismantlers or shredders; recyclers; or manufacturers. The headline and secondary indicators are presented in the following sections, the latter classified according to their nature, i.e. economic, criticality, recycling and dismantling indicators.

Table 2: Selected KPIs: type, field and links with platform modules

KPI	Type of indicator	Nature	Disassemblability module	Recycling module	Eco-design module
Metal use	Headline	criticality	X	X	X
Plastic use	Headline	recycling	X	X	X
Disassemblability	Headline	dismantling	X	X	X
Recyclability	Headline	recycling	X	X	X
Overall Score	Headline	global	X	X	X
Personnel cost	Secondary	economic	X		
Raw material cost	Secondary	economic	X		
Car part cost	Secondary	economic	X		
Metallic characterization of the car part in rarity terms (%tr)	Secondary	criticality			X
Metallic characterization of the car part in rarity terms (%wt)	Secondary	criticality			X
Plastic characterization of the car part	Secondary	recycling			X

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KPI	Type of indicator	Nature	Disassemblability module	Recycling module	Eco-design module
World recycling rates	Secondary	criticality			X
Automobile sector demand with respect to the annual production for a given metal	Secondary	criticality			X
Total cumulative demand with respect to known reserves for a given metal	Secondary	criticality			X
Supply risk	Secondary	criticality			X
Strategic metal index	Secondary	criticality			X
Most important world producer	Secondary	criticality			X
Production quote	Secondary	criticality			X
Difficulty level for Level 1	Secondary	dismantling	X		
Difficulty level for Level 2	Secondary	dismantling	X		
Material composition	Secondary	dismantling	X		
Disassembly time	Secondary	dismantling	X		
Recycling index of the entire car part	Secondary	dismantling		X	
Recycling rate of all individual materials in the car (sub) parts	Secondary	recycling		X	
Energy recovery	Secondary	recycling		X	
Global warming potential	Secondary	environmental			X

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5. Headline indicators

Indicators should help draw quick conclusions about what they monitor. For this reason, a set of so-called **Headline indicators** are proposed to give an overview of the car parts under different aspects. These indicators are shown at the head of each module of the Circularity Web application and are the following:

- **Metal use:** It indicates the criticality of the metals in the analyzed car part. Criticality is measured through the thermodynamic rarity indicator as explained in D3.1 and D2.1. and presented in the eco-design module (D4.7). This indicator ranges from 0 to 100.
- **Plastic use:** It presents the characteristics of the car part considering the plastic mixology. This indicator ranges from 0 to 100.
- **Disassemblability:** It presents the ease with which a car part can be disassembled and subdisassembled. The information presented in the disassembly module (D3.2 & D4.7) about disassembly levels is used to build this indicator. This indicator ranges from 0 to 100.
- **Recyclability:** It presents the recyclability of the entire car part using the metallurgical recycling processes defined in D3.3. This indicator ranges from 0 to 100.
- **Overall score:** It presents a global score of the car part, knowing the metal use, plastic use, disassemblability and recyclability indicators. This indicator is expressed in terms of stars (from 0 to 5 stars).

The next figure presents the mock-up of these indicators in each module's head of the Circularity Web application.

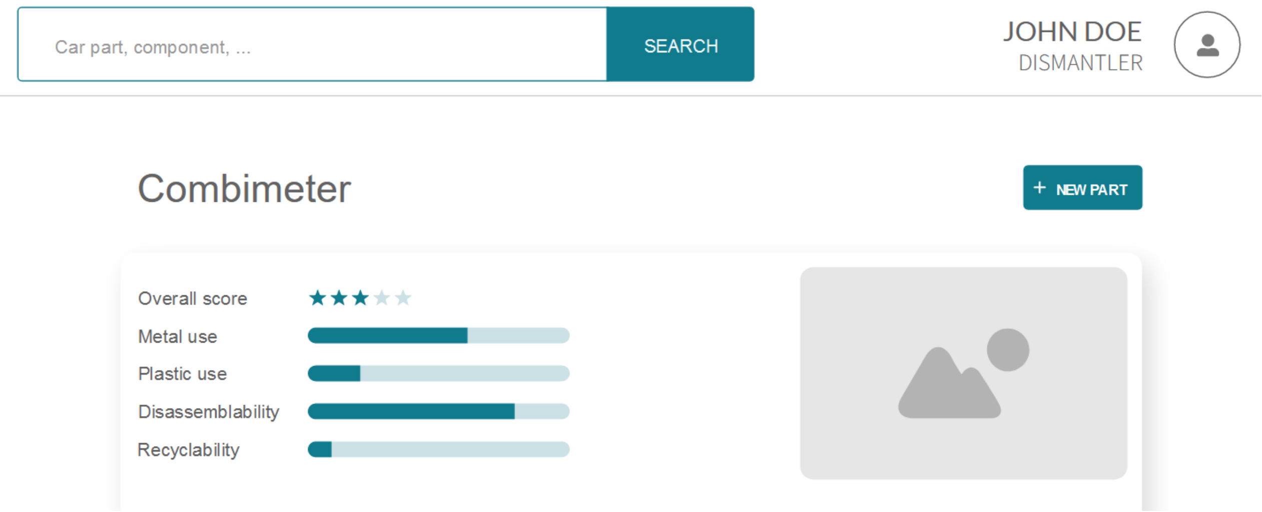

Figure 3: Headline indicators used in the head of disassemblability, recyclability and eco-design modules of the Circularity Web application. Source: D4.7.

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5.1. Metal use

As previously explained, the way to assess the resource efficiency in terms of metal use of the given car part is by means of the thermodynamic rarity indicator, previously explained in D.3.1, D2.1 and further elaborated in section 6.2. However, this indicator should be normalized so that a scale from 0 to 100 can be used. The normalization exercise can be conducted thanks to the activities carried out during Task 3.1, where a thermodynamic assessment of all car parts of different selected cars was performed. Accordingly, from the assessment made in all metallic car parts included in Leon II and Leon III models, it can be concluded that the thermodynamic rarity intensity (kJ/g) ranges from 0 to 4.800. However, the critical car parts (111) range from 200 kJ/s to 4.800 kJ/g (Ortego, Valero, Valero, & Iglesias, 2018), of which 90 % are between 200 kJ/g and 1.000 kJ/g.

Knowing this, the best value (100 points) is assigned to car parts with a thermodynamic rarity intensity below 200 kJ/g, while the worst is assigned for those car parts with a Rarity intensity ≥ 1.000 (kJ/g). Intermediate values are calculated through a weighted linear regression.

5.2. Plastic use

Given the high variety of plastics in the car, their recycling constitutes a tough challenge. It is no surprise that the amount of plastic recycled at the end of life of the vehicle is still very small; hence, the automotive sector is still far removed from closing the polymers cycle. The main measure currently used to increase circularity in cars is introducing recycled material from other sectors to manufacture new components.

In this sense, reducing the number of different polymers would enable higher recycling rates as there are fewer incompatibilities in the recovery processes. Incompatibility in plastics recycling has similar issues to metallurgical ones since certain mixtures generate low-quality plastics, hindering their market uptake for the same or for other applications. The ideal trend would be to evolve towards a mono-polymer vehicle, opting for those with well-developed recycling chains and processes.

However, more factors affect the sustainability of the car part in terms of its plastic use: (1) Number of main polymers; (2) Number of subcomponents in the car part with polymers; (3) Recycling compatibilities among the different polymers used; (4) Recycling compatibilities among additives used by the car part; (5) Use of adhesives; (6) Type of coating use in the car part; (7) Weight density compatibilities in the separation.

Given the limitations in the information available, this indicator will be only based on the share of the use of recycled material in the given car part. This information can be ideally obtained from MISS. That said, additional secondary indicators regarding the typology of the plastics use are provided in the eco-design module, as shown in section 6.4.

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5.3. Disassemblability

From D3.1 disassemblability and subdisassemblability levels were defined qualitatively as follows:

- Level 1 (disassembly the car part from the car): high / medium / low.
- Level 2 (subdisassembly the car part into subparts): high / medium / low.

From this information, the next table presents the disassemblability score depending on the different combinations that can occur at levels 1 and 2:

Table 3: Method to score disassemblability headline indicator

Level 1	Level 2	Score
High	High or not-possible	0
	Medium	12,5
	Low	25
Medium	High or not-possible	37,5
	Medium	50
	Low	62,5
Low	High or not-possible	75
	Medium	87,5
	Low	100

5.4. Recyclability

Recyclability indicators were first presented in D3.3. Among them, the Recycling Index is chosen as a headline indicator. It represents the recyclability of the car part as a whole, and it is ranked from A+++ (90 - 100 %) to G (0 to 10 %). The score as headline indicator is built directly from it, being the best score (100 points) assigned to A+++ car parts and the worst (0 points) to G car parts.

5.5. Overall score

This indicator summarizes the score of the car part from the headline indicators: metal use, plastic use, disassemblability and recyclability. It shows the number of starts (from 0 to 5), calculated as the average value of the headline indicators. The score is obtained as follows:

- 0 starts → $0 \leq \frac{Metal\ use + Plastic\ use + Disassemblability + Recyclability}{4} \leq 16$
- 1 starts → $17 \leq \frac{Metal\ use + Plastic\ use + Disassemblability + Recyclability}{4} \leq 33$
- 2 starts → $34 \leq \frac{Metal\ use + Plastic\ use + Disassemblability + Recyclability}{4} \leq 50$
- 3 starts → $51 \leq \frac{Metal\ use + Plastic\ use + Disassemblability + Recyclability}{4} \leq 67$
- 4 starts → $68 \leq \frac{Metal\ use + Plastic\ use + Disassemblability + Recyclability}{4} \leq 84$
- 5 starts → $85 \leq \frac{Metal\ use + Plastic\ use + Disassemblability + Recyclability}{4} \leq 100$

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6. Secondary indicators of the eco-design module

The eco-design module of the Circularity Web application is devoted to providing manufacturers with relevant information to improve the resource efficiency and circularity of future car parts. It incorporates a set of indicators aimed at characterizing car parts considering the criticality of the metals used, the plastic used, the associated environmental impact and their disassemblability and recyclability potentials (which are obtained from the dismantling and recycling modules, respectively).

It should be stated that the application can only generate information on already designed car parts, for which the compositional data and disassembly and recyclability assessments have been performed. That said, this data is valuable for manufacturers to understand the weak points of past designs and learn from the eco-design recommendations obtained from the application. Below is the list of selected indicators for the eco-design module.

6.1. Metallic characterization of the car part in mass terms (%wt)

This indicator aims to show the most abundant metals used in the given car part in a graphical way. To that end, the information obtained from MISS is processed to determine the quantity of all metals in the car part.

As most of them are not in the form of the metallic element, but as part of a compound, a conversion through the corresponding molecular weights should be carried out. This process will be automatized by the platform, as shown in D.4.7.

The contribution of each metal M_i to the total weight of the car part A can then be calculated with Eq. 1.

$$\%M_i(A) = \frac{m_i(A)}{\sum_{i=1}^{n} m_i(A)} x100 \;\; [g/g] \qquad \text{(Equation 1)}$$

The circularity web application will show the top 5 metals in mass terms, as shown in Figure 4 (left side).

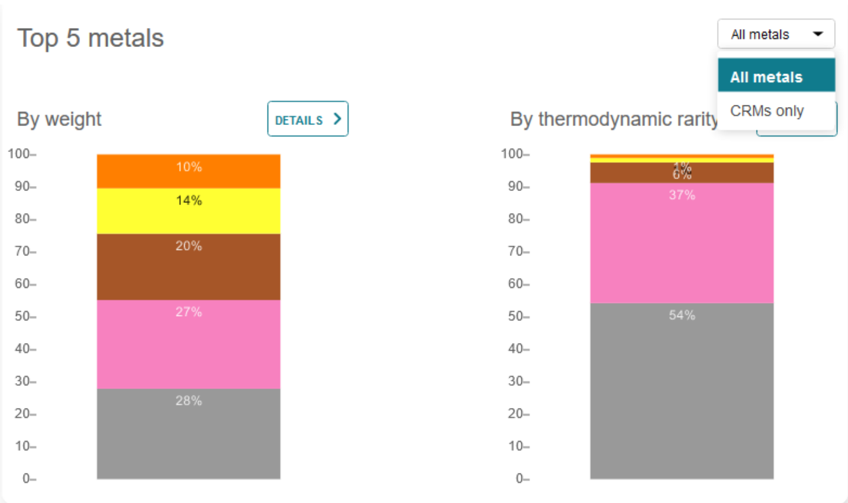

Figure 4: Example about weight and rarity ranking for a given car part. Source D4.7.

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6.2. Metallic characterization to the car part in thermodynamic rarity terms (%tr)

Expressing each metal's contribution to the car's total mass does not provide information regarding the criticality of the raw materials used. For instance, a gram of iron cannot be compared with a gram of gold.

We have selected the Thermodynamic Rarity indicator to measure the physical criticality of materials used in car parts. This indicator is based on the exergy property (a second-law derived property) and quantifies any commodity's value by adding two variables: the exergy replacement cost and the embodied exergy. The first one is defined as the exergy required to concentrate a given mineral from a dispersed state, called Thanatia (Valero & Valero, 2014) to the current concentrations found in the mines with prevailing technology. On the contrary, the embodied exergy, refers to the exergy associated to extract, beneficiate and refine the mineral to produce a commodity in the form necessary to be employed in industry.

Adding these two variables results in a given metal's thermodynamic rarity. This value gives an idea of the physical criticality of a given commodity in terms of its scarcity in the crust and the energy intensity required to mine and refine it. The following table shows these values for silver and copper as an example. As can be seen, the thermodynamic criticality of silver is 25 times higher than copper because the first is much scarcer in the crust, and the energy associated to mine and refine it is also much higher. The list of thermodynamic rarity values of all metals is available in D.3.1.

Table 4: Embodied exergy, exergy replacement cost and thermodynamic rarity of different commodities (Valero & Valero, 2014).

Metal	Embodied Exergy (kJ/g)	Exergy Replacement Cost (kJ/g)	Thermodynamic Rarity (kJ/g)
Ag	1,566	7,371	8,937
Cu	56	291	347

The Thermodynamic Rarity indicator has been used in D3.1 to identify and select the most critical parts for which a further disassemblability and recyclability assessment was performed in D3.2 and D3.3 (see a sample of this assessment in Table 5).

Table 5: Thermodynamic Rarity values for several car parts used in the SEAT León II

Car part	Thermodynamic Rarity (kJ)
Combi Instrument	683,932
Infotainment	583,423
Generator	512,000

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The contribution of the rarity of each metal R_i to the total rarity of the car part A can then be calculated with Eq. 2. knowing the thermodynamic rarity values of each element r_i (kJ/g) and the composition of any car part (g),

$$\%R_i(A) = \frac{m_i r_i}{\sum_{i=1}^{n} m_i r_i} x100 \text{ [kJ/kJ]} \qquad \text{(Equation 2)}$$

This indicator is then shown in a graphical way in the circularity web application (see Figure 4 right side).

6.3. Further information for each metal

The abovementioned indicators are then complemented with specific information about each metal, including world recycling rates, Automobile sector demand with respect to the annual production for a given metal, Total cumulative demand with respect to known reserves for a given metal, supply risk, strategic metal index and most important world producer and production quote. This additional information help manufacturers in the decision-making process when selecting metals for new car part designs.

6.3.1 *World recycling rates (WRR)*

For manufacturer, it is important to know how easy it is to find secondary sources from any commodity if they want to incorporate recycled materials to manufacture a car part.

For this purpose, the world-recycling rate is proposed as one indicator in the eco-design module. This indicator is constant for any commodity and the source of data comes from the recycling rates published by the United Nations Environmental Programme about world recycling figures of metals (The United Nations Environmental Programme (UNEP), 2011).

The WRR unit is expressed as a percentage (%), it always refers to functional recycling and includes recycling as pure metal (i.e: copper) and as alloy (i.e: brass).

is calculated as the quantity of any commodity recycled in a close loop to be used again as it was the primary source of this metal. As an example, the WRR for iron is higher than 50 % while for REE is smaller than 1%.

6.3.2 *Automobile sector demand with respect to the annual production for a given metal (A)*

To calculate this indicator, the automobile cumulative demand and the total cumulative demand of all industrial sectors up to 2050 for each studied metal are used.

Dividing the cumulative demand of the automobile sector by the total cumulative demand from 2018 to 2050 gives an idea about the importance and dependency of the automobile sector in the world capacity production of each metal. On the other hand, it also informs about the potential competition that might exist for that given metal with other sectors.

As an example, this indicator has a value of 53 % for cobalt, while it is only 1 % for chromium. It means that the dependency and contribution of the automobile sector for cobalt extraction up to 2050 is very relevant and insignificant in the case of chromium.

The figures of this indicator for any commodity were published by UNIZAR partners in a scientific paper (Ortego, Valero, Valero, Iglesias, et al., 2018).

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6.3.3 Total cumulative demand with respect to known reserves for a given metal (B)

This indicator is defined as the known resources with respect to total cumulative demand (up to 2050) of each metal. Mineral resources are based on current geological knowledge. They are concentrations of solid materials of economic interest which are not economically extractable at the time of determination but that have a grade, quality, quantity of form that could make them extractable in the future. There is some uncertainty associated with resources information as, obviously, the Earth's composition and mineral concentrations cannot be fully studied in every part of the planet due to economic limitations. The available information depends on the exploration carried out by mining companies, which usually tend to focus on more profitable minerals and large deposits. Still, resource information remains approximately constant over time compared with reserves or reserves base information and can be used for our calculations (Calvo et al., 2016).

Resources values from different sources have been analyzed, and those more accurate and that presented data for most of the metals included in the study have been used (Emsley, 2001; L. E. Frenzel & Frenzel, 2016; M. Frenzel et al., 2014; Sverdrup & Ragnarsdottir, 2014). In the case of rare earth element (REE), information is usually aggregated, so data from Haque et al (Haque et al., 2014) has been used for individual REE, combined with information from other sources.

The figures of this indicator for any commodity were published by UNIZAR partners in a scientific paper (Ortego, Valero, Valero, Iglesias, et al., 2018).

6.3.4 Supply risk (C)

Supply risk is related to the countries that produce those elements if it is produced spread between many countries or concentrated only in a few ones, including as well the governance performance of those producing countries, the import reliance of the EU, a supply risk based substitution index, etc.

In more detail, this supply risk parameter is calculated as follows (Eq. 3) (European Commission, 2020):

$$C = \left[(HHI_{WGI,t})_{GS} \cdot \frac{IR}{2} + (HHI_{WGI,t})_{EUsourcing} \cdot \left(1 - \frac{IR}{2}\right)\right] \cdot (1 - EoL_{RIR}) \cdot SI_{SR} \quad \text{(Equation 3)}$$

Being *HHI* the Herfindahl-Hirschmann Index, *WGI* the world governance index, both used as a proxy for country concentration and governance, respectively, *IR* the import reliance, EoL_{RIR}, the end-of-life recycling input rate and SI_{SR} the substitution index.

This SR parameter ranges from 0 to 10 and so to use it in the SMI index it is extrapolated to a 0 to 100 scale.

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6.3.5 Strategic metal index

The SMI is a global indicator that accounts for the three aforementioned variables (A, B and C) by means of using weighting coefficients for each one, as follows (Eq. 4):

$$SMI = \alpha \cdot A + \beta \cdot B + \gamma \cdot C = A' + B' + C' \quad \text{(Equation 4)}$$

Each coefficient (α, β and γ) can have values ranging from 0 to 1, depending on the importance that the constraints could have in each variable. For this endeavor, the following three coefficients are assigned: 0.33, 0.66 and 1.

In the case of the share of the material demand of vehicles compared to the total demand (variable A), the higher the percentage of materials used by the vehicle sector is, the higher is the dependence and thus the vulnerability of this sector. For this reason, 1 is assigned to materials whose A value is higher than 30%, 0.66 is assigned to values between 10 and 30%, and 0.33 to values lower than 10%.

For variable B, that is the comparison between cumulative total demand from 2018 to 2050 and current known mineral resources, if this demand represents more than 30% of mineral resources, the value assigned is the highest one, 1, as it could compromise future availability of this element. If this value is between 10 and 30%, the value assigned is 0.66, and if this demand represents 10% or lower of current known mineral, resources, it is assumed that the risk of shortages is lower, and the value assigned to the coefficient is 0.33. Still, it must be considered that to calculate the cumulative total demand, the material demand from other sectors has been considered constant from 2018 onwards.

As for variable C, the supply risk, the highest value is assigned to materials who have a supply risk higher than 4 (over a scale of 10), 0.66 is assigned to materials who have a supply risk between 1 and 4 and 0.33 to materials that have a supply risk lower than 1.

The figures of this indicator for any commodity were published by UNIZAR partners in a scientific paper (Ortego, Valero, Valero, Iglesias, et al., 2018).

6.3.6 Most important world producer and production quote

This information complements the supply risk indicator mentioned above, by providing the name of the most important world produce country of the given commodity, with the corresponding production share. For instance for cobalt, the most important world producer is Congo while its contribution to the total production is 59 %, what constitutes a clear supply risk. This information comes from United States Geological Surveys reports annually published (USGS, 2017).

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6.4. Plastic characterization of the car part

The information provided through MISS files makes it possible to characterize the car part in terms of its plastic content. All plastic types p_i will be grouped into: PP, PA, PU, EPDM, PET, ABS, PC, PVC, POM, PVB and others and their corresponding share $\%P_i(A)$ will be calculated with Eq. 3 and represented as in Figure 5.

$$\%P_i(A) = \frac{p_i(A)}{\sum_{i=1}^{n} p_i(A)} x100 \ \ [g/g] \qquad \text{(Equation 3)}$$

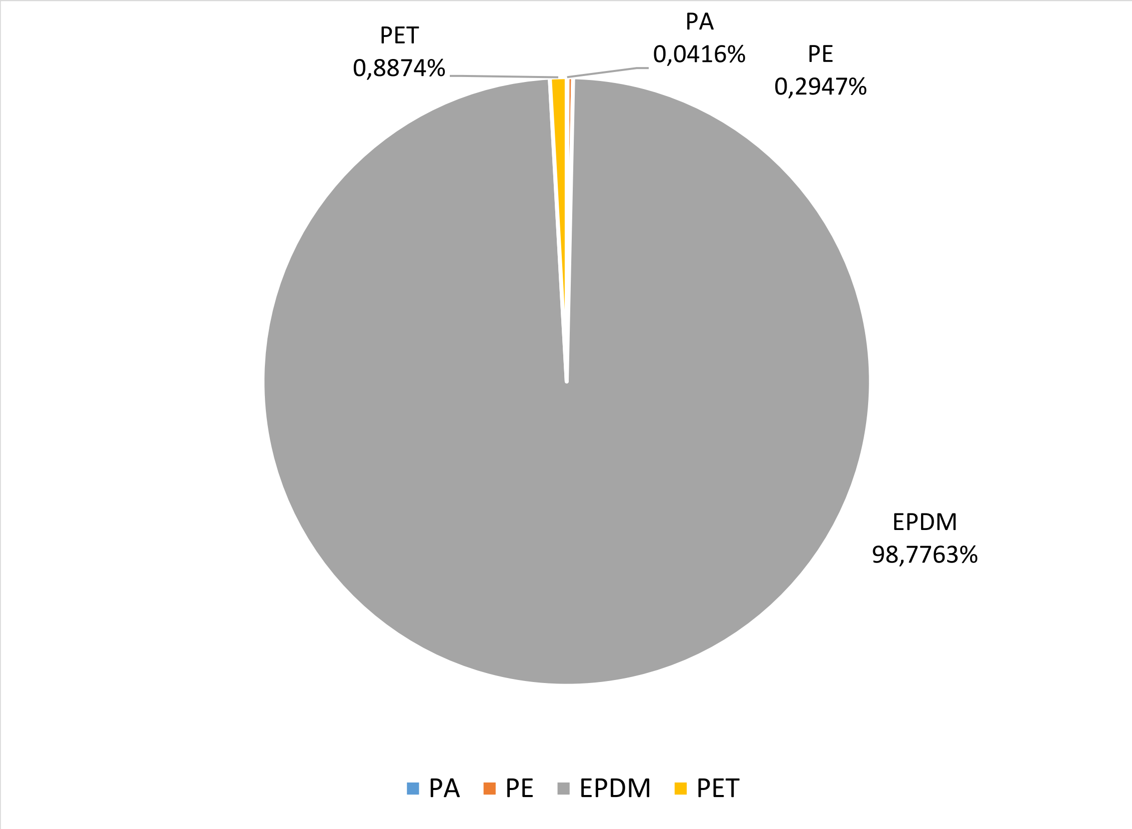

Figure 5: Example of plastic characterization for a given car part – Window guide Leon Gen II

An additional grouping of plastics into: thermoplastics, thermosettings and non-classified plastics will be provided as an indication of the ability of the given car part to incorporate recycled material (which is favored when mainly thermoplastics are used).

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6.5. Global warming potential

This environmental indicator comes from SEAT and shows information about the global warming potential associated to a given car part. To be calculated, the following stages and hypotheses are taken into account:

1) The life cycle stages are manufacturing, use, and end of life.
2) Manufacturing considers mining and refining of raw materials, car part building, and assembly in the plant.
3) In manufacturing, it is assumed that all raw materials come from primary sources excluding the input of recycling fractions.
4) In the use stage, polluting emissions (CO, PM, NOx) come from the limits defined by EURO Directives and the emissions homologated by the emission and fuel consumption test cycles.
5) The number of kilometers in this stage are 150.000 km.
6) Maintenance operations are exclude from the use stage.
7) The end of life accounts only the depolluting operations.

GWP is calculated using the software GaBi from the inventory and the hypothesis described as measured in kg CO2-eq. As an example, an additional brake light use in SEAT Leon Gen II has 3,33 kg CO2-eq.

7. Secondary indicators: Disassemblability module

7.1. Material composition

Knowing the material composition is an incentive to disassemble a car part because of the value of the materials it contains. This indicator will represent the material composition in four categories (the input for metallurgical processes): plastics, ferrous metals, aluminium, non-ferrous metals (excluding aluminium). The information will be given in percentage (%) over the total composition.

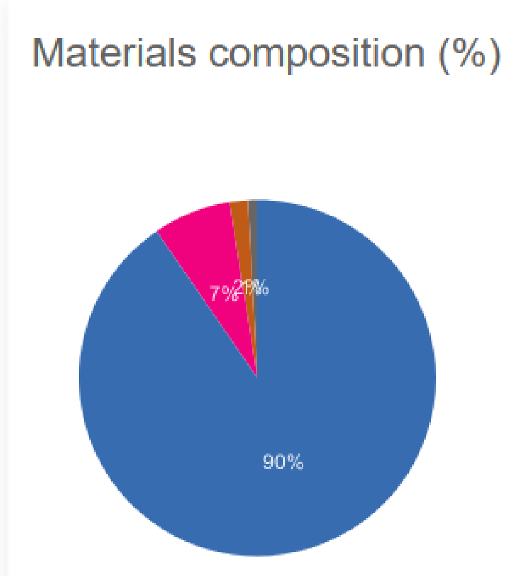


Figure 6: Visualization of material composition information in the dissasembly module. Source: D4.7.

Material composition as a disassembly indicator will offer information to encourage that car part be disassembled and latterly send to recycling plants for applying metallurgical operations. Moreover, these 4 fractions (plastics, ferrous, non-ferrous (excluding aluminium) and non-ferrous (aluminium) are easily identified so dismantlers even can subdisassembly a car part and get these fractions (see next figure) to obtain more remuneration for them.

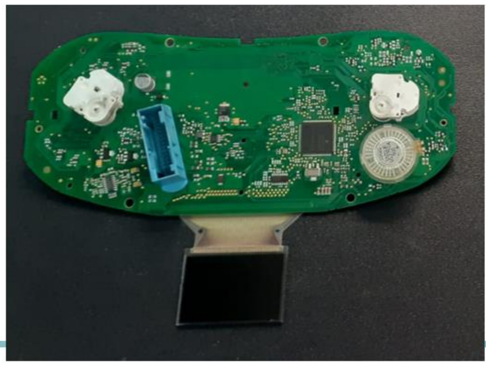
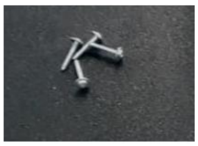
Plastics	Non-ferrous metals-excluding Al	Ferrous metals
		

Figure 7: Recycling fractions obtained from the infotainment of SEAT León II. Source: D3.2.

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7.2. Raw material cost

The raw material cost represents the market value of each commodity embedded in the analyzed car part (€/ton). This information helps dismantlers to identify and recover car parts with valuable raw materials, which can then be sent either for reuse or for proper recycling.

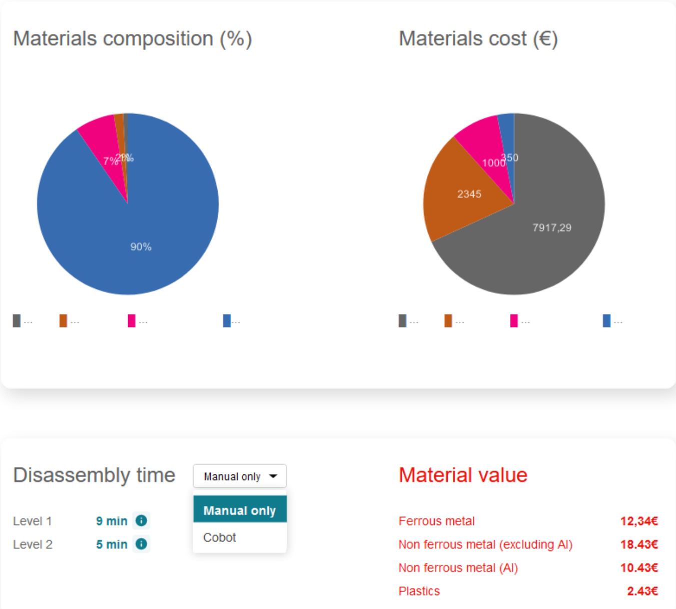

Figure 8: Information about material costs presented in TREASURE disassemblability module. Source: D4.7.

7.3. Disassembly time

The disassembly time is an indicator used to provide information about the time needed to make a given dismantling operation at levels 1 and 2, in minutes. It should be remembered that in D3.2 three disassembly levels were defined:

- Level 1: The car part is disassembled from the car.
- Level 2: The car part is subdisassembled in subparts, if is possible.
- Level 3: Different subparts are grouped in recycling fractions for metallurgical processes. These fractions are: plastics, ferrous metals, non-ferrous metal (aluminium), non-ferrous metals (excluding aluminium). Level 3 is only achievable when the outputs of Level 2 are rich in any recycling fraction.

The visualization of the indicator in the disassemblability module for Level 1 and 2 is presented in the next figure. Beyond the time, this indicator can be filtered to show the information according to the type of operation: manual or through cobots. D 3.2 performed dismantling activities for over 100 car parts. This information will be included in the platform. That said, the objective is that dismantlers populate directly the platform with this information.

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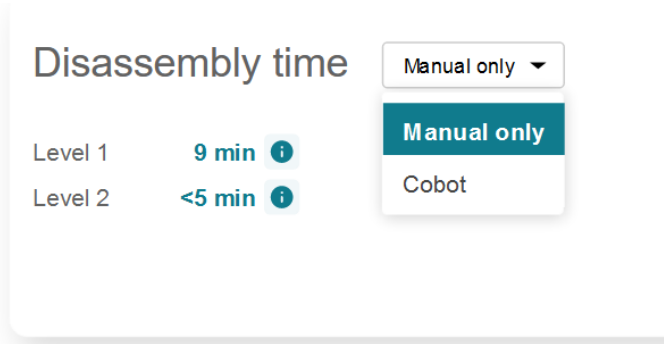

Figure 9: Disassembly time indicator. Source: D4.7.

7.4. Difficulty level for Level 1

This Level represents the car part's difficulty in extracting it from the car. For example, an infotainment is easier to dismantle as a rear mirror (see next figure) because no other parts need to be removed to extract it from the car. For the rear mirror, the door panel must be disassembled before.

Figure 10: Disassembly Level 1 for infotainment (left) and exterior mirror (right). Source: D3.2.

This indicator is qualitative, and it has three possible values: high / medium / low. The selection depends on the following variables:

- The total number of tools needed to disassemble the car part.
- The type of tools. They can be standard or specific to this operation. Sometimes manufacture design specific tools for specific operations.
- The number of car parts which are needed to be disassembled before.
- If more than, one person is needed to make it.

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Considering this variable, the value is assigned following the boolean logic described in the next table.

Table 6: Difficulty level calculation process in Level 1

Difficulty Level	Number of tools		Type of tools		Number of parts to be disassembled before		More than 1 dismantler needed?
High	>5	OR	non standard	OR	>3	OR	YES
Medium	(1-5)	AND	standard	AND	(1-3)	AND	NO
Low	1	AND	standard	AND	0	AND	NO

7.5. Difficulty level for Level 2

As in the previous case the difficulty level 2 has three possible values: high / medium / low. Nevertheless, fewer variables are needed to calculate the value in this case because the car part is already outside the vehicle. Moreover, once a car part is out of the vehicle, a single person can undertake additional operations.

As a result, the difficulty level is calculated by considering the number and type of tools needed to subdisassemble the car part. In the next table, the boolean logic proposal is presented.

Table 7: Difficulty level calculation process in Level 2

Difficulty Level	Number of tools		Type of tools
High	>5	OR	non standard
Medium	(1-5)	AND	standard
Low	1	AND	standard

7.6. Personnel cost

The personnel cost represents the salary in €/h of a disassembler. This indicator is used in the disassemblability module to calculate the feasibility of disassembling operations considering disassembly times.

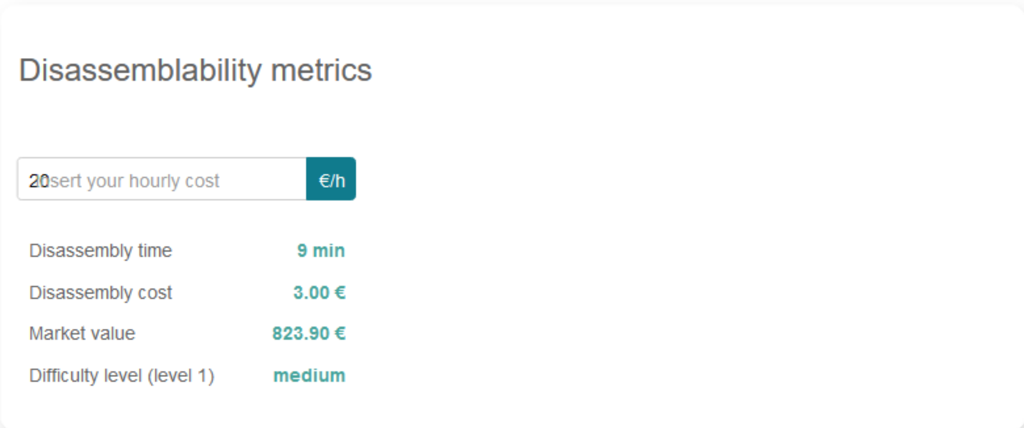

Figure 11: Information about personnel cost asked by the platform in the disassemblability module. Source: D4.7.

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7.7. Car part cost

The car part cost (€) represents the market value of the car part. It is useful for dismantlers as it encourages expensive car parts to be disassembled for reuse.

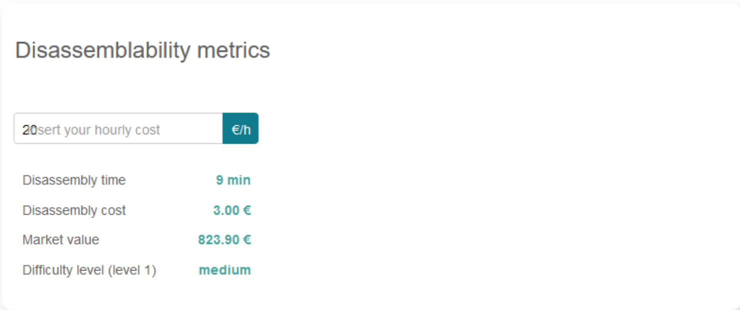

Figure 1: Information about car part cost. Source: D4.7.

8. Secondary indicators: Recyclability module

Recyclability indicators are presented by MARAS in D3.3 to assess the recyclability of the entire car (sub) parts as well as their composing materials. Recycling KPI's are calculated by the application of rigorous and physics-based process simulation models incorporating the full compositional detail of the car parts, which are recovered through metallurgical processing and energy recovery flowsheets. It includes the complex interlinkages of functional materials as well as all chemical transformation processes in the reactors in the system model in versatile flowsheet simulation modules. Recycling KPIs are calculated for the entire car or sub-part as well as for all individual materials/compounds/elements composing the parts under consideration. This is done based on the basis of all mass flows, recoveries and losses for all metals/materials and elements/compounds (both on physical as well as chemical level) in the processing flowsheet(s) applied to recover the materials.

The starting point of recycling (and simulations) is to create material and metal products, alloys, compounds etc. of a functional quality so that these can be used in the same product these have originated from. This would be true circularity. Three different levels of circularity have hence been defined to assess the recycling results (i.e. (1) closed loop CE recycling, (2) open loop CE to be processed into closed loop CE and (3) open loop CE recycling (see D3.3 for further details).

The recycling performance is not only determined by it's composition and build-up, but depends also on the recycling route applied/selected from the full range of industrially BAT recycling processing infrastructures which is available to recycle the car part and its materials (see Figure 3).

For the most optimal processing of the car parts under consideration, three different suitable recycling routes have been defined from the full metallurgical recycling infrastructures as available as presented by Figure 12.

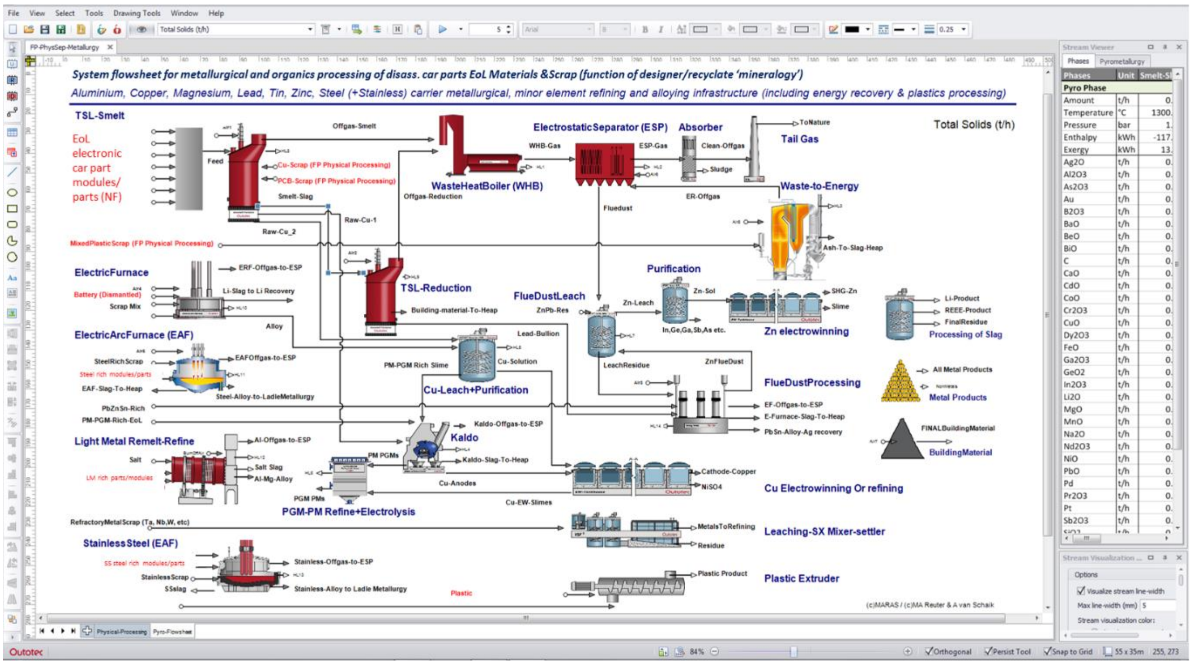

Figure 12: The metallurgical, energy and plastics processing flowsheet for (electronic) car parts and complex EoL products as industrially available to process the multitude of metals, alloys, functional materials and plastics in an end-of-life product as included in the recyclability assessment. Source (D3.3).

The different disassembled car parts and/or disassembled sub-parts are directed into the recycling flowsheet simulation model following the segments in the Metal Wheel as shown in Figure 13, which is covered in the simulation models by the complete flowsheets and range of reactors composing the different (metallurgical) processing infrastructures. On this basis, the effect of the different recycling processing routes on the recyclability can be determined and the most optimal/suitable recycling processing flowsheet for the part under consideration can be determined. Based on the car part compositional build-up, the following processing routes have been assessed to be the most suitable options for the different car parts: (1) Copper processing route; (2) Steel processing route and (3) Energy recovery.

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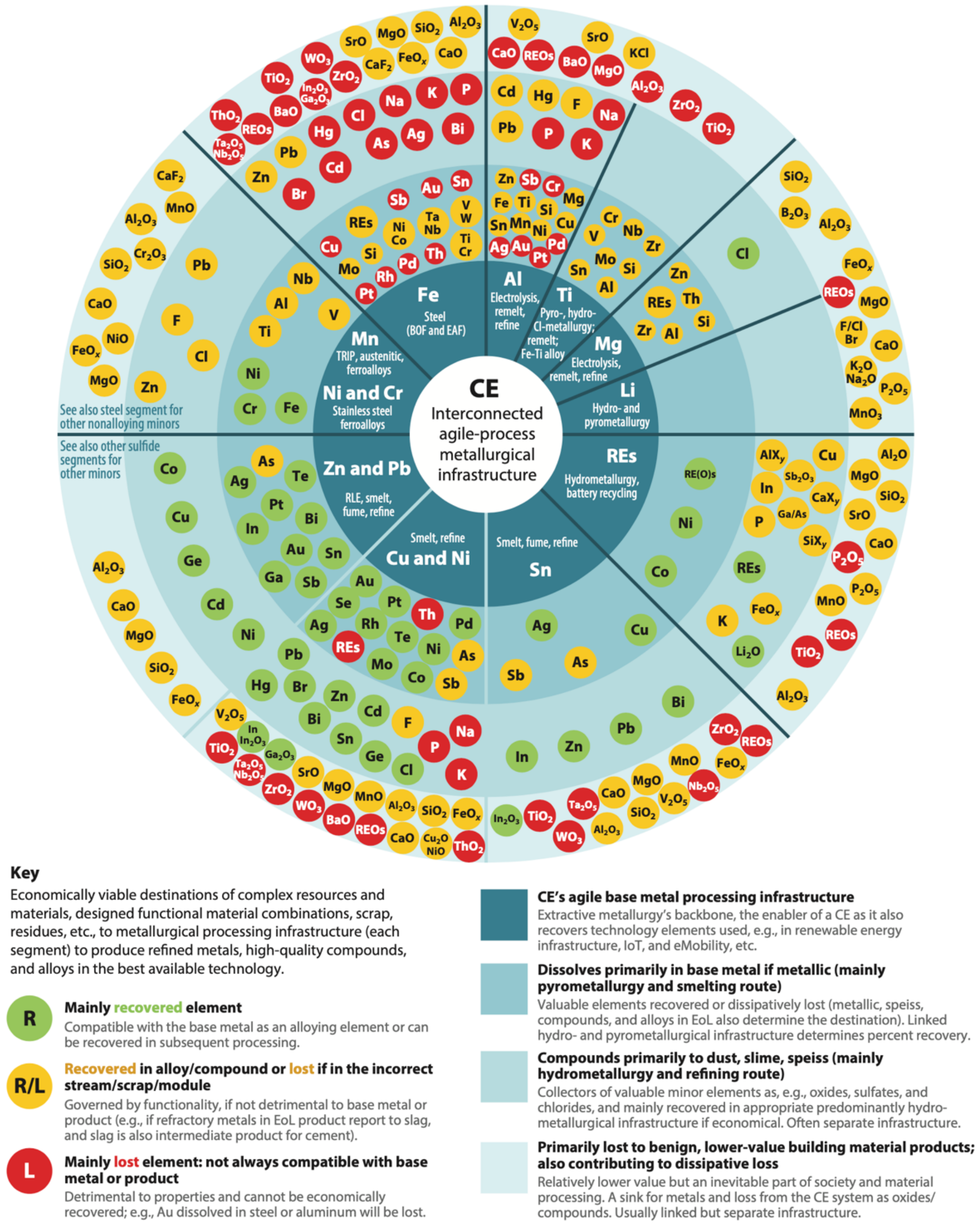

Figure 13: The Metal Wheel, based on primary metallurgy but equally valid for metals recycling reflects the destination and hence recoverability or losses (in-compatibility) of different elements in a product/component for different interlinked metallurgical processes (Reuter and Van Schaik, 2013)

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The recyclability module of TREASURE platform will provide the following indicators:

- Total recycling rate, which can be visualized by the Recycling index of the car part as a whole (%).
- Individual material recycling rate of all materials/elements/compounds included in the car part (e.g. Fe, Cu, Au, Ag, CRM recycling rate, etc) in % which can be visualized by the Material Recycling Flower.
- Energy recovery in MWh/t of feed or per car part.

8.1. Recycling Index of the entire car part [%]

The recyclability assessments as performed for the different recycling routes, result in the calculation of recycling KPIs, i.e. recycling rates of the total car part (calculated as mass based recycling percentages). These can be visually presented by the Recycling Index for the different car parts, processing routes assessed and different levels of recycling in terms of CE. recyclability of the entire car part is presented. The Recycling Index allows for an easy to understand format of presenting recycling rates and a comparison of different recycling routes and car part recycling performance at once glance (all underlying recycling rates and mass flow data is available from the modelling). The Recycling Index presents the recycling KPIs in a classified format and at a scale ranging from A+++ (90 - 100 %) to G (0 to 10 %). The next figure shows an example for the recycling of the Infotainment unit from the Leon II processed in the copper route (comparable figures are also given for the other processing routes and car parts and for the recycling of sub-parts obtained through additional disassembly as defined in D3.2).

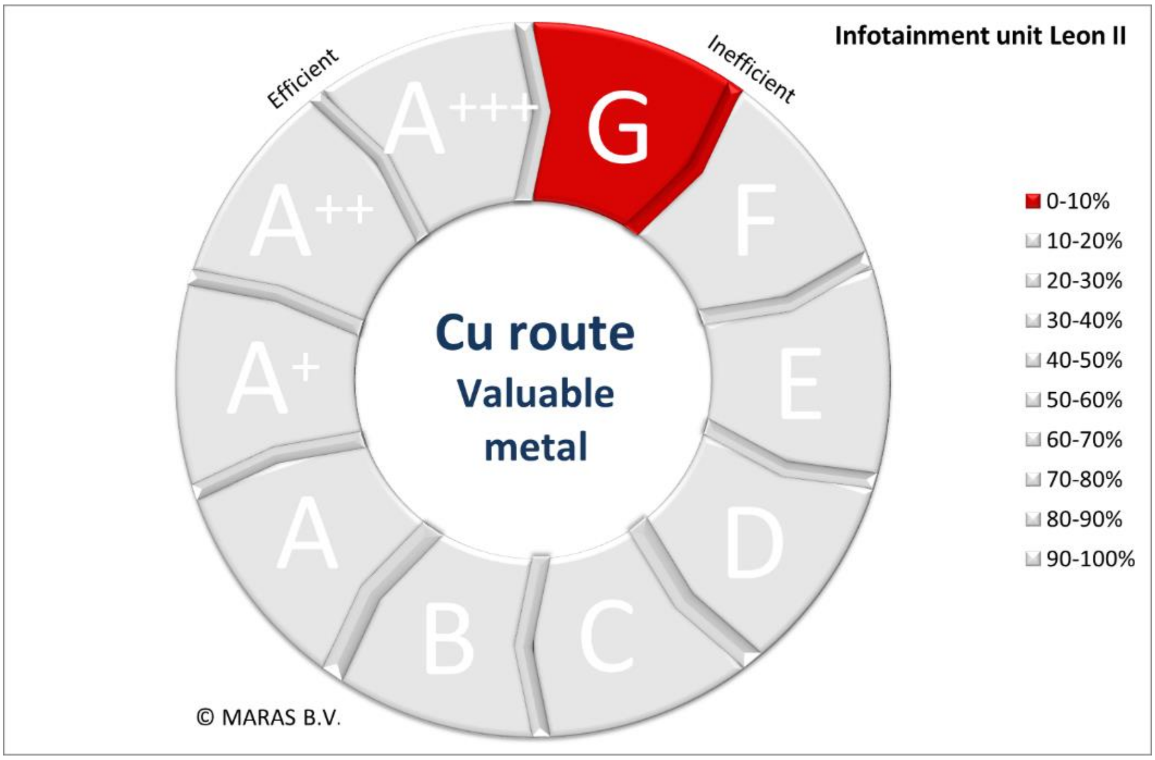

Figure 14: Recyclability of the entire car part. Source: D3.3.

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8.2. Recycling rate of all individual materials in the car (sub) parts

Whereas the overall recycling rates provide information on the recyclability of the entire part or product, the individual recycling rates/KPIs are the basis for true CE assessment. Recycling of complex products is a trade-off between bulk and minor element recycling, where often the one material will (to a more or lesser extent) be 'sacrificed' for the recovery of the other. This is not always reflected by the overall recycling rates due to the lower weight of precious (scarce, critical) elements present). Therefore, individual recycling rates are important KPI's calculated from the recycling assessment models. The Material Flowers as developed by MARAS serve very well as a tool in this discussion and help to make the choice for a certain recycling route, not only driven by weight based considerations, but addressing the recycling of materials and elements, which are of interest to recycle or defined as critical and therefore require focus in selecting the most optimal recycling options. Comparing individual material recycling rates is crucial in this discussion. Also Design for Recycling requires the detail of individua material recycling rates. The individual recycling rates as calculated in the recycling assessment quantitatively support and guide, which options in both additional disassembly and/or DfR will have the highest impact in improvement of recyclability.

The recycling rate of each material/element/metal is implicitly calculated in the recycling assessment. The individual material recycling rates can be visualised by the use of the Material Recycling Flower as it is explained in D3.3. Figure 15 presents an example of this tool in which a selection of materials and their recycling rates are presented for the case of the Leon II recycled in the Cu route (all other values for all materials/compounds/elements are available through the model) Around the flower the different materials are described and the recycling rate of each one is presented from red (0-10 %) to green (90-100 %). A closed green circle in the centre of the figure would imply a closed EoL CE.

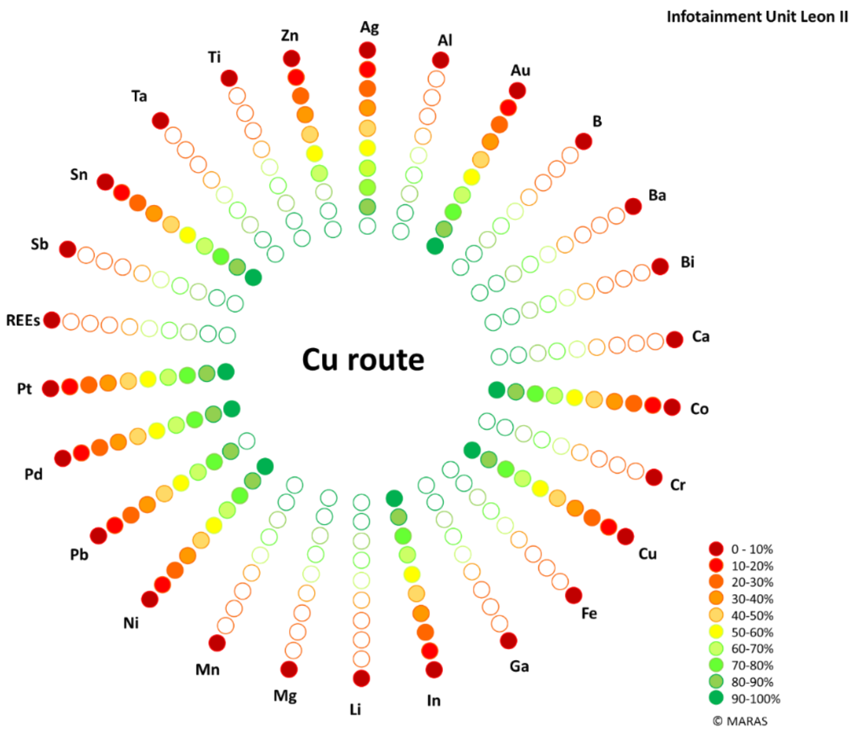

Figure 152: Material Recycling flower

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8.3. Energy recovery

Most car part are characterised by a relatively high percentage of organics/plastics. Energy recovery from feed is included as a recycling KPI as organic content will be used in some of the processing routes as an energy carrier from which the energy content is (partially) recovered (e.g. in the Cu processing route, organics are also used as reductant). Energy recovery is also dependent on the required extra energy input to the process as a consequence of the low metal content/low grade of the car part recycling input. This indicator is also included to present the results of the energy recovery route and also allow for comparison with the energy recovery which also occurs in e.ge. the Cu route.

The energy recovery indicator is represented as MWh/t of feed or per car part.

9. Conclusions

This deliverable gathers the results obtained in deliverables D2.1, D2.2, D3.1, D3.2 and D3.3 regarding proposed indicators, from which the KPIs to be included in the different modules of the Circularity Web application of the platform are selected. In total 26 KPIs are presented being 5 of them headline indicators.

The 26 KPIs can be classified into economic, criticality, dismantling, recycling and environmental indicators. Social indicators, addressed in detail in D2.2, are out of the scope of the Circularity Web application but are considered in other parts of the platform.

It must be underlined that the available information conditions the KPI selection. Accordingly, most KPIs proposed can be obtained directly from the MISS database provided by car manufacturers. Other KPIs are easily obtained through available information sources or input data gathered from the different stakeholders through the TREASURE platform.

The proposed KPIs are already integrated into the first version of the Circularity Web application of the platform (D4.7). That said, this selection might slightly change in future versions of the platform, considering the progress of other work packages.

References

Calvo, G., Mudd, G., Valero, A., & Valero, A. (2016). Decreasing Ore Grades in Global Metallic Mining: A Theoretical Issue or a Global Reality? *Resources*, *5*(4), 36. https://doi.org/10.3390/resources5040036

Emsley, J. (2001). *Nature's Building Blocks: An A–Z Guide to the Elements. Oxford, England, UK: Oxford University Press.*

European Commission. (2020). *Study on the EU's list of Critical Raw Materials (2020) Final Report*. https://doi.org/10.2873/904613

Frenzel, L. E., & Frenzel, L. E. (2016). Chapter Twenty-Two – On-Board Diagnostics (OBD) II. In *Handbook of Serial Communications Interfaces* (pp. 97–99). https://doi.org/10.1016/B978-0-12-800629-0.00022-X

Frenzel, M., Kertris, M. P., & Gutzmer, J. (2014). On the geological availability of germanium. *Mineralium Deposita*, *49*(4), 471–486. https://doi.org/10.1007/s00126-013-0506-z

Haque, N., Hughes, A., Lim, S., & Vernon, C. (2014). Rare Earth Elements: Overview of Mining, Mineralogy, Uses, Sustainability and Environmental Impact. *Resources*, *3*, 614–635. https://doi.org/doi.org/10.3390/resources3040614

Ortego, A., Valero, A., Valero, A., & Iglesias, M. (2018). Toward Material Efficient Vehicles: Ecodesign Recommendations Based on Metal Sustainability Assessments. *SAE International Journal of Materials and Manufacturing*, *11*(3), 213–228. https://doi.org/10.4271/05-11-03-0021

Ortego, A., Valero, A., Valero, A., Iglesias, M., & Villacampa, M. (2018). Strategic metal ranking for the automobile sector. *Sustainable Development of Energy, Water and Environment Systems*.

Sverdrup, H. U., & Ragnarsdottir, K. V. (2014). *Natural resources in a planetary perspective*. Geochemical Perspectives, volume 3, number 2. https://doi.org/10.7185/geochempersp.3.2

The United Nations Environmental Programme (UNEP). (2011). *Recycling rates of metals. A status report.* http://wedocs.unep.org/bitstream/handle/20.500.11822/8702/-Recycling rates of metals%3A A status report-2011Recycling_Rates.pdf?sequence=3&isAllowed=y

USGS. (2017). *Publications and Data products*. https://minerals.usgs.gov/minerals/pubs/

Valero, A., & Valero, A. (2014). *Thanatia, the destiny of the Earth's mineral resources*.